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Foreword

The National Aeronautics and Space Administration and the Atomic Energy Commission have established a Technology Utilization Program for the dissemination of information on technological developments which have potential utility outside the aerospace and nuclear communities. By encouraging multiple application of the results of their research and development, NASA and AEC earn for the public an increased return on the investment in aerospace research and development programs.

This document is one of a series being employed to disseminate such information and is divided into two sections. The first section presents analyses of various materials, concerning their responses to stimuli such as heat, cold, stress, and so on. Section two presents similar analyses, but relates to structures. While the great majority of items were developed during aerospace research and development, the materials and structures involved are of interest to the industrial community.

Additional technical information on individual devices and techniques can be requested by circling the appropriate number on the Reader Service Card included in this compilation.

Unless otherwise stated, NASA and AEC contemplate no patent action on the technology described.

We appreciate comment by readers and welcome hearing about the relevance and utility of the information in this compilation.

Jeffrey T. Hamilton, *Director*
Technology Utilization Office
National Aeronautics and Space Administration

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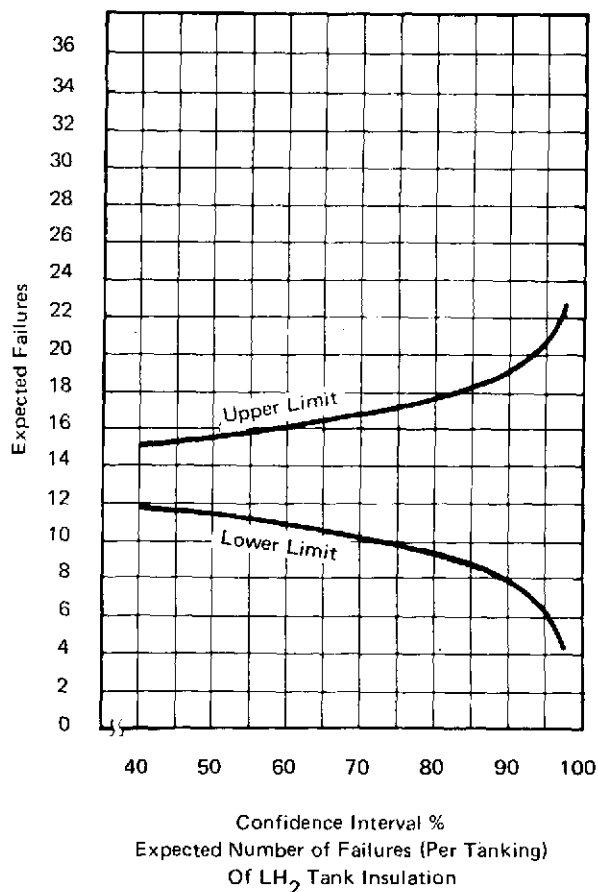
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Section 1. Material Analysis

STATISTICAL ANALYSIS OF FAILURES IN CRYOGENIC TANK INSULATION

Failure probability predictions related to confidence intervals have been made by statistical analysis of the failure history of cryogenic (LH_2) tank insulation. While the data was obtained during cryogenic tankings of the Saturn V stages S-II-1 and S-II-2, they are applicable to any large-area, thin-walled storage container for cryogenics.



The analysis of the number of failures of all types, discovered after each tanking, revealed that the probability of at least one failure per tanking asymptotically approaches 100% as shown in the Figure and in the Table. The final step in accomplishing the objectives of this study was to perform a data reduction and statistical prediction analysis, calculating upper and lower limits of expected failures for a specified confidence interval. The results are shown in the Table and the Figure.

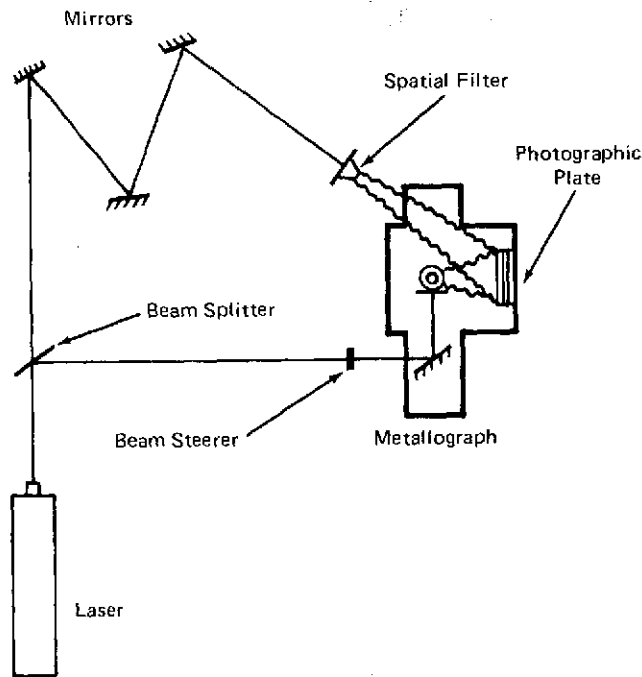
Expected Number Of Failures
Per Tanking With Corresponding
Confidence Interval

Confidence Interval	Interval Of Expected Failures	
	Upper Limit	Lower Limit
98%	23	4
95%	21	6
90%	19	8
80%	18	9

Source: C.N. Masters Jr. and
R. A. Venditti of
The Boeing Company
under contract to
Marshall Space Flight Center
(MFS-14379)

Circle 1 on Reader Service Card.

HOLOGRAPHIC STRESS ANALYSIS



A device for nondestructive testing of solder joints has been developed. The holographic method is believed to be the first positive technique for correlating stress with load to predict printed circuit board lifetime.

The laser light is divided into two beams by a beam-splitter, as shown in the figure. The transmitted beam is reflected from a series of mirrors through a spatial filter to a photographic plate. The filter increases the spatial coherence of the beam by filtering out unwanted modes. The reflected beam passes through a beam steerer into a metallograph. The metallograph illuminates the test sample and relays the image to the photographic plate. A hologram is produced by the two beams striking the plate. The magnifying power of the metallograph may be varied from 1X to 2000X, depending on the inspection area desired.

Since the hologram stores both phase and amplitude information, it can be used in two ways to determine the stress in solder joints. In the first method, a double-exposed hologram is used. The first exposure is made with the test sample under no load. A load (thermal, mechanical, etc.) is applied and the second exposure made. The hologram then reveals the displacements in the test sample caused by the stress,

as a set of fringes around the image of each part of the test sample. The fringe spacing indicates the amount of displacement — the larger the displacement, the smaller the fringes. Thus, the relative motion of each component on the test sample can be determined and by knowing this, the amount of stress induced by the load can be calculated.

The second method produces the same results, but it operates on a real-time basis. A hologram of the test sample under no load is made, developed, and returned to its original position in the apparatus. When this is done, the image produced by the hologram is exactly superimposed on the original test sample, so that if no change occurs, only the illuminated sample is seen through the hologram. When a stress is applied, fringes will appear as the displacements occur, and the development of fringes may be observed in real time. The analysis of stress from the observed fringes is the same as in the first method.

Source: J. R. Williams
Marshall Space Flight Center
(MFS-20687)

Circle 2 on Reader Service Card.

DETERMINING LOAD CARRYING CAPABILITY OF FILAMENT-WOUND COMPOSITE MATERIALS

An analytical procedure, for determining critical buckling loads of both orthotropic and isotropic filament-wound composite cylinders, subjected to axial compression loading, has been developed. Both general instability and local instability modes have been considered; classical netting theory and conventional theory of discontinuity were applied to analyze lined pressure vessel test configurations. The superior characteristics of high strength and minimum weight exhibited by filament-wound composite materials indicate their potential in the shipbuilding and pressure vessel industries. Additional applications include the aircraft and chemical industries, and in structural hardware requiring low weight and high strength configurations.

The theory of analyzing a metallic or filament composite structure subjected to internal or external pressures has been well established. However, based on a literature survey, there is only limited theoretical information available regarding the general instability of filament composite structures subjected to pure axial compression. Therefore, this analytical approach was formulated for determining the axial compressive load carrying capability, applying a more rigorous treatment of axial, transverse, and shear modulus of elasticity of the composite material than previous studies (metallic shells). As a result, the key parameters used for buckling stress evaluation for filament composite shells proved very different from those for metallic structures. This analytical technique, when completely verified by tests, may be used in design for sizing filament composite-stiffened or monocoque cylinder elements of various configurations, and for analytically predicting their load carrying capability.

A theoretical equation was derived to predict the buckling failure stress for the general instability mode of failure. Derivation of this equation included consideration of large deflection theory and initial imperfection level in conjunction with the well known principles of strain energy and work.

This study and analysis have produced the following results:

(1) Application of the general instability stress equation for stability critical filament composite cylindrical shell structures offers a significant weight saving of about 36% over the equal sized aluminum construction. Use of netting theory stress equations for metal lined filament composite pressure vessels offers a weight saving of about 47% over aluminum, 55% over HY-140 steel, and 25% over maraging steel. These predicted weight saving results are consistent with industrial test data recently surveyed. The high strength/modulus-to-weight ratios of boron and graphite composites make them desirable for monocoque stability-critical shells.

(2) Diffusion-bonded boron filament-aluminum (6061) matrix laminate showed remarkable longitudinal, transverse, and shear stiffness which resulted in a much larger compressive load carrying capability, particularly for a stiffened configuration with ring reinforcement. Weight savings in this type of stiffened composite shell could be greatly increased if composite reinforced rings are used in place of the aluminum rings.

(3) Boron filament-epoxy matrix with stainless steel liner may be suitable for pressure vessel construction subjected to elevated temperature environments.

(4) High strength lightweight S-glass filament-epoxy resin matrix with aluminum (6061-T6) liner should be considered for cryogenic tank applications for low cost and lightweight objectives.

Source: P. B. Yang and
W. H. Armstrong of
The Boeing Company
under contract to
Marshall Space Flight Center
(MFS-15121)

Circle 3 on Reader Service Card.

STUDY OF HIGH-TEMPERATURE BEARING MATERIALS

An experimental investigation has identified materials suitable for use in potassium lubricated turbo-generator journal bearing and shaft applications at temperatures from 480 to 1150 K (400° to 1,600°F). Much of the information obtained during the program appeared useful in other high-temperature bearing applications.

From a compiled list of 100 materials, 14 candidates were selected for detailed evaluation, singly and in combination. The candidates represented five broad classes of materials: nonrefractory metals and alloys, refractory metals and alloys, Fe-Ni-Co bonded carbides, refractory compounds (oxides, carbides, borides), and refractory metal-bonded carbides.

Evaluation of the materials was based on the following experimental information:

- 1) Friction and wear behavior in high vacuum (10^{-9} torr; no lubrication).
- 2) Friction and wear behavior under boundary lubrication with liquid potassium.
- 3) Compatibility in potassium in Cb-1Zr.
- 4) Dimensional stability.
- 5) Strength.
- 6) Hardness.
- 7) Wettability by potassium.

Particular attention was given to the predicted chemical stability of the materials. Also, two separate service temperature regimes were established: above 810 K (1000°F) and below 810 K (1000°F). The higher temperature simplifies system design. The lower simplifies bearing materials selection.

The most appropriate materials for this service were: TiC + 10% Cb, commercial cobalt-bonded carbides (e.g., carboloy 907 or equivalent material), a cold-pressed and sintered alloy of tungsten and molybdenum. The first two groups of material were applicable above 810 K (1000°F) and the third applicable below 810 K (1000°F).

Additional documentation is available from:

National Technical Information Service
Springfield, Virginia 22151
Price: \$3.00
Reference: TSP69-10252

Source: R. G. Frank of
General Electric Co.
under contract to
Lewis Research Center
(LEW-10829)

Circle 4 on Reader Service Card.

THERMAL CONDUCTIVITY AND DIELECTRIC CONSTANT OF SILICATE MATERIALS

An analytical and experimental investigation of the thermal conductivity and dielectric constant of nonmetallic materials has been reported. Principal emphasis was placed on evaluating the mechanisms of heat transfer in evacuated silicate powders and establishment of the complex dielectric constant of these materials.

Experimental measurements of the complex dielectric constant of glass beads, powdered pumice, powdered basalt, and solid glass, pumice, and basalt were made at wavelengths of 3.2 cm and 1.2 cm over the temperature range from 77 to 400 K. The thermal

conductivity of these materials and quartz powders was measured using the line heat source method at gas pressures of 10^{-8} to 10^{-9} torr and at temperatures ranging from 150 to 400 K.

The dielectric constants, of the silicate powders measured, vary from 1.9 to 2.9. The loss tangents of these materials vary from about 0.004 to 0.030. The dielectric constants of the solid silicates, from which the powders were prepared, range from 5.4 to 8.6.

The effective thermal conductivities of the evacuated powders of particle size 5-75 microns vary from about 4×10^{-6} W/cm°C to near 40×10^{-6} W/cm°C

over the temperature range from 150 to 400 K, and can be represented by the sum of a constant term and a term which has a cubic temperature dependence. The ratio of the radiation to solid conduction contributions, to effective thermal conductivity, varies from less than 0.1 to over 5 depending upon the powder size, composition, and temperature.

Experimental measurements and results are related to postulated lunar surface materials. The dielectric parameters are important for the interpretation of

radioastronomical and radar observations of lunar and planetary surface properties, and may be of interest to mineralogists working with other silicates.

Source: A. E. Wechsler and I. Simon of
Arthur D. Little, Inc.
under contract to
Marshall Space Flight Center
(MFS-14856)

Circle 5 on Reader Service Card.

FIBERGLASS-REINFORCED STRUCTURAL MATERIALS FOR AEROSPACE APPLICATION

Fiberglass-reinforced plastic materials have been extensively investigated to evaluate their potential usefulness in aerospace structures. These materials are of particular interest for such applications because of their low density, unidirectional strength, low thermal conductivity, and machinability. Possibly the greatest potential of the materials is in their proposed use as tension supports for cryogenic tanks.

The investigation was carried out along four lines. These were: (1) a literature survey; (2) conceptual design, detail design, and analysis; (3) development of a manufacturing plan, identification of process controls, and fabrication of parts; and (4) preparation of a test plan, testing, and analysis of results.

The literature survey resulted in the selection of composite materials and adhesives that could be expected to have the best characteristics at ambient and cryogenic temperatures. Epoxy resins and fiberglass reinforcements were the materials chosen for experimental evaluation. The specific structural elements investigated were tension rods, tubular struts, and I beams. Comparisons were made with their metallic counterparts to determine the thermal and weight advantages of using fiberglass reinforced plastic structures. The tension rods and tubular struts were considered for cryogenic tank supports, and

were compared with similar members made from low-thermal conductivity alloys. The beams were conceived as payload support members where light weight, rather than low thermal conductivity, was of primary concern.

It is concluded from the investigation that fiberglass construction offers some weight saving when compared with aluminum alloy construction in the case of beams and struts. A greater potential of the fiberglass material is realized in cryogenic tank supports, as the result of its low thermal conductivity and its strength. Therefore, in cases where stiffness design criteria prevail and thermal conductivity is not a factor, advanced composites employing filamentary materials of boron or carbon are believed to be more competitive with metallic materials.

Source: D.H. Bartlett of
The Boeing Company
under contract to
Marshall Space Flight Center
(MFS-14806)

Circle 6 on Reader Service Card.

FRICTION CHARACTERISTICS OF GRAPHITE AND GRAPHITE-METAL COMBINATIONS AT VARIOUS TEMPERATURES

Certain useful characteristics of the coefficient of friction of graphite and of graphite combinations between 300 K (70°F) and about 2477 K (4000°F) are reported. The combinations studied included graphite with graphite, carbide and metals (aluminum alloys, stainless steels, and Inconel X-750), and carbide with carbide. The major factors investigated were (1) surface finish and "wear-in"; (2) surface conditioning: influence of atmospheres and outgassing; (3) temperature; and (4) interfacial pressure.

Graphite's good frictional quality is attributed to a gas film on surface platelets; thus the surface finish greatly influences the wear-in characteristics. When one of the surfaces is graphite, the static coefficient of friction at room temperature in air, hydrogen, or vacuum wears-in to a value of about 0.18 for surface pressures within the "elastic" range.

With increase in temperature, the coefficient for graphitic combinations in hydrogen decreases, the static value being about 0.1 at 2477 K (4000°F). This effect of temperature is reversible: the coefficient increases with cooling, returning to almost the same

room-temperature value. The coefficient of friction for graphite-metal combinations decreases with temperature until a surface reaction occurs, after which it increases.

Removal of the surface film, by outgassing at 1670 K (2540°F) in vacuum, raises the static coefficient [in vacuum at 300 K (70°F)] from about 0.18 to more than 0.4; this value returns to about 0.18 when hydrogen is admitted to the surfaces so that the gas film is restored.

Niobium carbide on niobium carbide has a room-temperature static coefficient of friction of 0.19 in air, hydrogen, or vacuum; this value increases with temperature, reaching unity at about 2200 K (3500°F).

Source: M. J. Manjoine of
Westinghouse Astronuclear Lab.
under contract to

AEC-NASA Space Nuclear Systems Office
(NUC-10151)

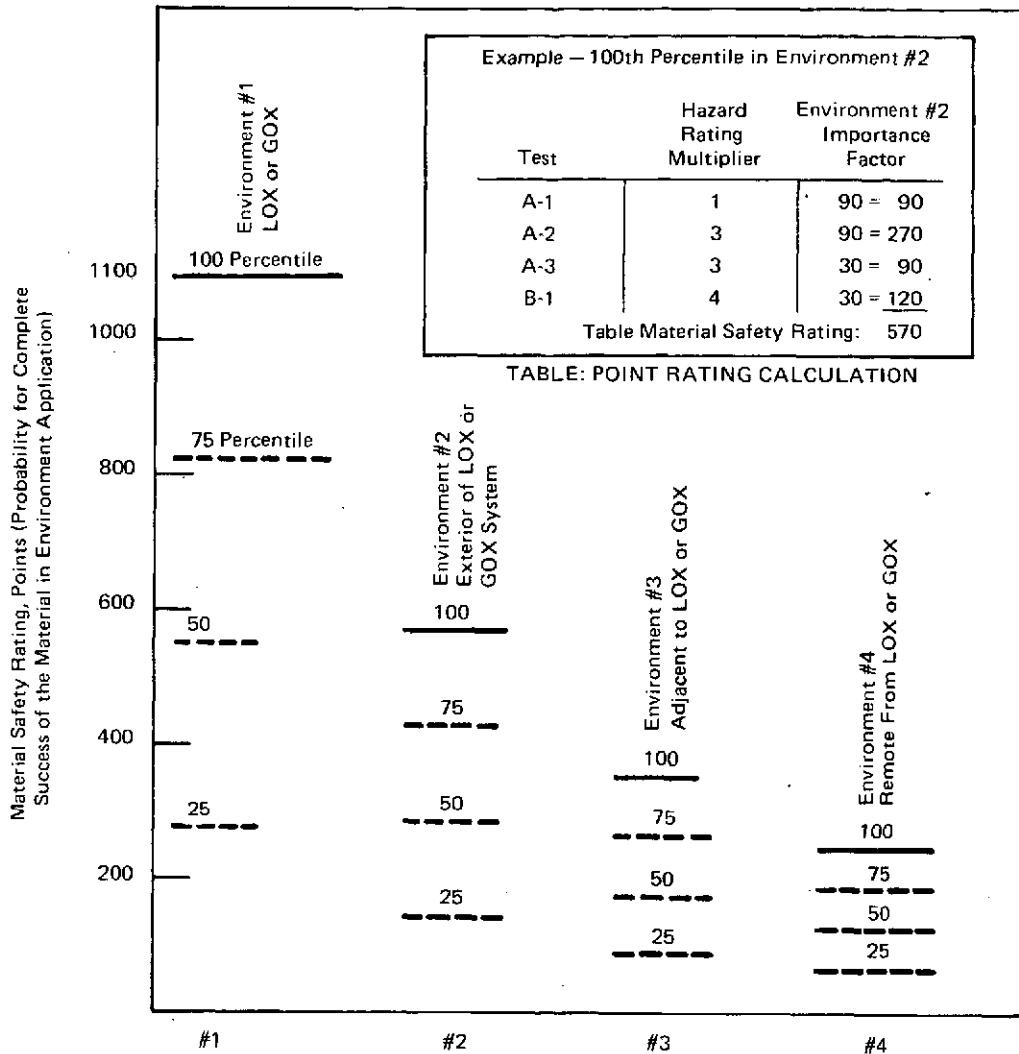
Circle 7 on Reader Service Card.

COMPATIBILITY AND FLAMMABILITY OF ENGINE INSULATION MATERIALS

A program was conducted to establish liquid oxygen (LOX) or gaseous oxygen (GOX) impact compatibility and air flammability of rocket engine insulation materials and systems. Seventeen basic materials were tested along with four insulation systems comprised of combinations of materials selected from the seventeen basics. A materials rating system was devised to rate the safety of material applications, based on the environmental hazard to which the material or system is exposed. For the rocket engine applications, the environmental hazards were divided into 4 categories: (1) Materials used in LOX or GOX systems; (2) Materials for the exterior of LOX or GOX systems; (3) Materials used on the exterior and adjacent to but not in contact with LOX or GOX; and, (4) Materials used remote from LOX or GOX systems.

The rating system employs a sliding scale, with the flexibility to modify, add to, or subtract from the procedure. To develop the system, two conditions

were postulated; the first is that the flammability and compatibility tests can be used as a fire hazard classification and a numerical value is thus assigned. This value is termed the Hazard Rating Multiplier and is assigned for three separate categories; ignitability, burning characteristics, and burning rate. The second postulation is that the hazard to a material in a system is a function of the environmental application (i.e., a material used in LOX or GOX is in a more hazardous environment than the same material in air). Therefore, the rating system was devised to place judgment on the aspect of various environment applications by employing Degree of Importance Factors. The factors vary from 1 to 100 with 1 being the lowest degree of importance, 10 being the median, and 100 the most critical. The importance scale employs a logarithmic projection so that the differences between 70, 80, and 100 are minor. Each material is assigned a safety rating in points which can be translated to a percentile rating



for different environments. The table shows how the maximum or 100 percentile rating is calculated for a sample environment. Each of several flammability tests (A-1, A-2, etc.) is listed with its Hazard Rating and Degree of Importance. A more complete rating system could include further tests. For each test, the product of the Hazard Rating Multiplier and the Degree of Importance is a subtotal for that test. The subtotals are added to give a total safety rating in points. The example in the table is for tests in an environment equivalent to the exterior of a LOX or GOX system.

The chart shows that, although the 570 points for the example in the table correspond to the 100th percentile for Environment #2, a material with that rating would fall only slightly above the 50th percentile in the more severe Environment #1.

Source: J. H. Lieb of
 Rockwell International Corp.
 under contract to
 Marshall Space Flight Center
 (MFS-18981)

Circle 8 on Reader Service Card.

EVALUATION OF POLYMERIC PRODUCTS IN THERMAL-VACUUM ENVIRONMENT

An investigation was conducted to qualify commercial polymeric products for use in a thermal-vacuum environment (125°C , 10^{-5} torr). Approximately 350 materials were screened for outgassing characteristics, of which 100 qualified within the limits of less than 1% weight-loss and less than 0.1% VCM (volatile condensable material) content. Approximately 20 products were examined in great detail and proved satisfactory. They retained their mechanical and electrical properties through decontamination cycles and exposure to the specified thermal-vacuum conditions.

The theory of the release and condensation of substances from polymers exposed to a thermal vacuum environment was evaluated. Equipment and procedures for identifying and measuring the release of VCM were developed, as well as test equipment and techniques for evaluating the effects of decontamination and thermal-vacuum exposure on specific properties of the polymeric products.

Infrared absorbance spectra of the VCM from 96 polymeric products and an interim list of recom-

mended products were identified. All of the examined products are listed in an alphabetical index; an acceptance rating, based on test results, is assigned to each one.

The following documentation may be obtained from:
National Technical Information Service
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Single document price \$6.00
(or microfiche \$0.95)

Reference:
NASA-CR-89557 (N67-40270),
Polymers for Spacecraft Applications

Source: R. F. Muraca and J. S. Whittick of
Stanford Research Institute
under contract to
NASA Pasadena Office
(NPO-11288)

THERMAL AND STRUCTURAL MODELING OF TELESCOPES

Technical data on the feasibility of modeling thermal and structural performance of space telescopes, using basic analytical and experimental approaches, has been compiled. Thermal modeling of large space telescope systems was based on a scale model of the 2-meter Optical Technology Apollo Extension System (OTES) space telescope experimentally associated with the Lunar Excursion Model (LEM) vehicle. Investigations were made into such thermal design parameters as insulation quality, structural member conductance, thermal control coating surface properties, and sun shutter operating factors. It was shown that model tests compared favorably with analytical predictions; and reinforced the premise that a passive thermal control technique would suffice for thermal control of telescope interiors.

One advantage of such a model is that it permits direct physical measurement of the thermal response of critical components, thus providing flexibility for systems studies and design changes.

The following documentation may be obtained from:
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Reference:
NASA-CR-98241 (N69-16957), Thermal and Structural Modeling of a Large Aperture Space Telescope

Source: R. E. Rolling, K. N. Marshall,
and D. O. Murray of
Lockheed Missiles and Space Co.
under contract to
Marshall Space Flight Center
(MFS-20324)

MECHANICS OF DEFORMATION AND FRACTURE OF FIBROUS COMPOSITES

Filaments of very high strength and stiffness have created considerable interest in their combination with appropriate matrix materials to provide fibrous composites that take advantage of these outstanding properties. Studies have been made of the influence of both fiber and matrix characteristics upon the mechanics of deformation and fracture of fibrous composites. A report summarizing the findings of these studies has been prepared, presenting the information needed to select appropriate constituents for given applications. These studies consider the response of a matrix reinforced by uniaxially-oriented fibers. The strength of such a material is treated for the cases where the failure criteria are maximum tensile and compressive loads carried by the composite in a direction parallel to the fiber orientation.

When the response of a composite is to be measured in terms of average stress and average strain, the material can be represented by an effective homogeneous but anisotropic material having the same average response. For the case of a matrix containing uniaxially-oriented fibers, the effective material is transversely isotropic and is therefore characterized by five elastic constants. Various analytical approaches to the evaluation of these constants as functions of the constituent properties have been made and the relationship between constituent properties and elastic moduli is reasonably well understood.

However, when a fracture criterion is desired, an understanding of the average stress-strain response is no longer sufficient, and consideration must be given to internal irregularities in the state of stress. The report treats these problems for both ultimate compressive and tensile strengths.

The failure of a fibrous composite under a uniaxial compressive load is considered first. A possible failure mechanism for this case is the hypothesis that the individual fibers buckle in a short wavelength pattern, in a fashion analogous to the buckling of a column or plate on an elastic foundation. An approximate evaluation of the influence of fiber geometry and fiber and matrix moduli upon the composite compressive strength can then be made. These results are compared to the results of an experimental program

which utilized hollow and solid glass fibers in several matrix materials. The test specimens were short columns designed to achieve a compressive strength failure.

The major portion of the report is devoted to a study of the mechanics of tensile failure of a fibrous composite. The study is based upon consideration of the phenomena which occur subsequent to an initial internal fracture. The strength of the brittle fibers is considered to be defined by a statistical distribution function. Thus, the initial fracture is likely to occur in a fiber. The resulting perturbation of the local stress field is treated. An approximate solution indicates the nature of the interface stress distribution as well as stress concentrations in nearby fibers. This stress field could result in adjacent fiber fracture, that is, a crack propagation effect, or in separation along the interface. A third possibility is that the stresses in the vicinity of an initial fiber fracture do not produce further fracture and that increasing load produces a distribution of fiber fractures corresponding to the initial distribution of weak points in the fibers. The continued accumulation of these fractures would produce a weak cross section at which the remaining unbroken fibers could no longer transmit the applied load. Instantaneous tensile failure would then occur.

A statistical tensile failure model of a fibrous composite is established on this basis, and the mechanical characteristics of fiber and matrix are utilized to obtain a statistical failure definition. An experimental program to investigate the validity of the model is described, and an attempt is made to correlate the tensile properties of constituents and composites.

Additional details of this study are contained in: Mechanics of Composite Strengthening, by B. Walter Rosen, General Electric Co.

Source: B. W. Rosen of
General Electric Co.
under contract to
NASA Headquarters
(HQN-10035)

Circle 9 on Reader Service Card.

EROSION OF METALS BY MULTIPLE IMPACTS WITH WATER

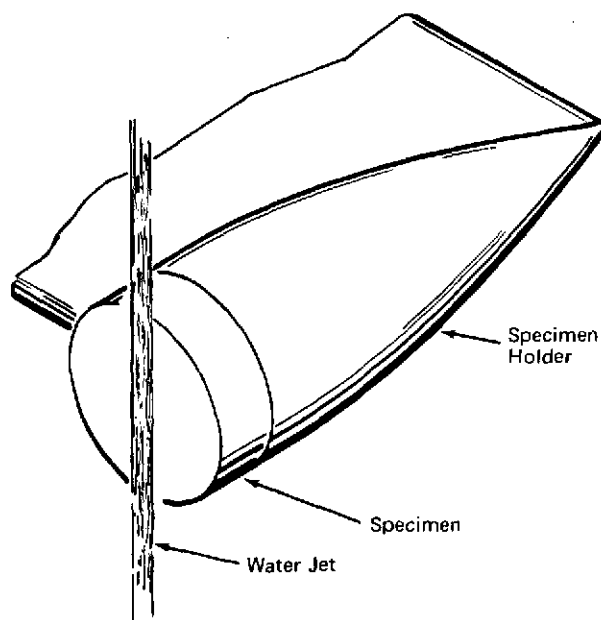


Figure 1. Water Erosion Test

Analytical and experimental investigations were conducted on the erosion of four metals by multiple impacts with water. The metals were: aluminum-1100-0; type-316 stainless steel; annealed commercially pure nickel; and an annealed titanium alloy, Ti-6Al-4V. Preliminary data were obtained for three turbine materials: Steelite-6B, Udimet-700, and molybdenum alloy TZM.

Specimens mounted on a disk, rotating horizontally at speeds up to 20,000 rpm, cut vertical jets of tap water at 293 K (68°F) twice per revolution (Fig. 1). The impact velocity is related to the minimum number of impacts causing visible indentation.

For the four metals, the fatigue strengths were experimentally determined as functions of the numbers of cycles to failure, using a high-frequency fatigue apparatus (Fig. 2). These data were correlated with the impact velocity data, in terms of the water-hammer pressure.

The erosion rates were determined as functions of the test durations at different velocities. These data

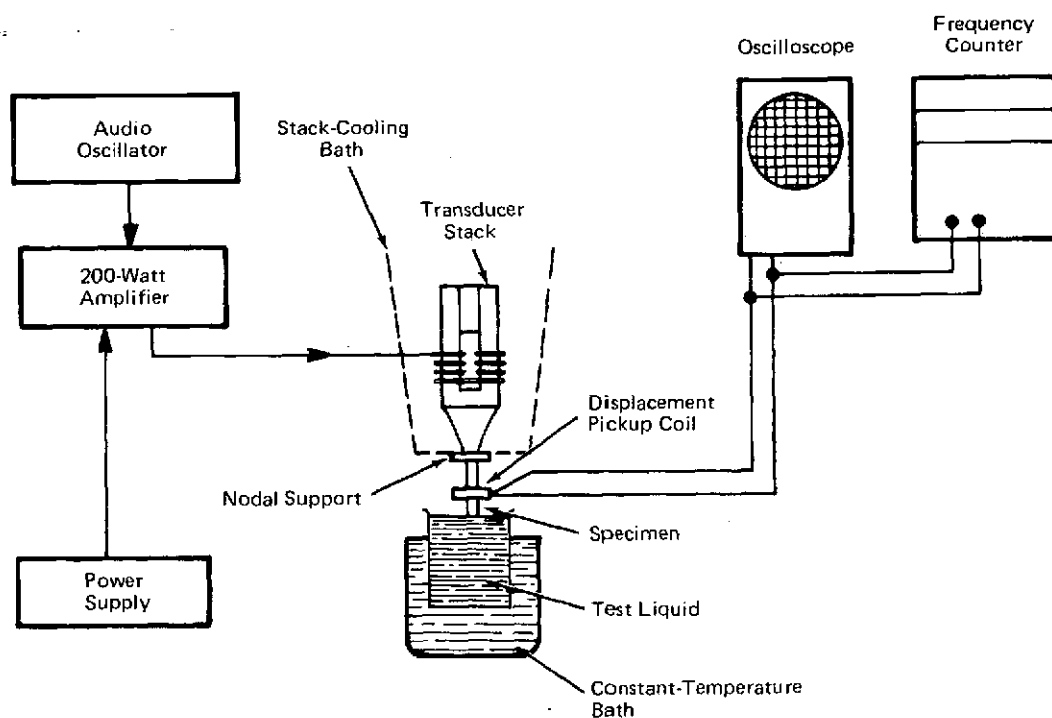


Figure 2. High Frequency Fatigue Apparatus

were then compared with a recently developed theory of erosion. The fatigue-life distribution curves were also determined.

The specific objectives of the investigation were to: (1) determine the relation between impact velocity and the minimum number of impacts producing visible erosion; (2) determine the relation between high-frequency fatigue stresses and the number of cycles to failure; (3) determine the relation of water-hammer stresses (corresponding to impact velocities) to the high-frequency endurance limit; (4) determine the rate of erosion as a function of exposure time; (5) correlate the experimental data with a recent theory; (6) evaluate the erosion rate's dependence on the velocity of impact; and (7) compare the liquid-impact and cavitation-erosion strengths for the four metals.

The following documentation may be obtained from:

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Reference:

NASA-CR-1288 (N69-19786), Experimental and Analytical Investigation on Multiple Liquid Impact Erosion

Source: A. Thiruvengadam and S. L. Rudy of
Hydronautics, Inc.
under contract to
NASA Headquarters
(HQN-10591)

A CONCEPT FOR IMPROVING THE DIMENSIONAL STABILITY OF FILAMENTARY COMPOSITES IN ONE DIRECTION

An analytical investigation was conducted into the design of filamentary composites having high strength and stiffness, and a zero thermal coefficient of expansion in one direction. Advanced filament materials, such as boron, used in three-dimensional reinforcement configurations, demonstrated substantial advantages over conventional filamentary composites.

Calculated strength, stiffness, and density of selected composites designed to give zero thermal coefficients of expansion in one direction compared favorably with such structurally efficient materials as the better titanium alloys. An analysis of three-dimensional reinforcement configurations revealed a capability for substantially enhancing strength properties, particularly for loadings where shearing stresses inclined at angles to the filaments are critical. Calculated stiffness properties of the three-dimensional reinforcement configurations proved generally superior to those of planar, two-dimensional reinforcements.

A major contribution of this study is the quantitative demonstration of enhanced shear strengths provided by three-dimensional reinforcement at angles to the filaments. The fact that the quantitative increases have been calculated to be so substantial should

provide impetus to the development of such three-dimensionally reinforced composites.

Guidelines were established for the characteristics of the filamentary material, binder, and reinforcement configuration required to achieve filamentary composite with a zero thermal coefficient of expansion in one of its principal directions. Analysis methods were developed for the evaluation of the elastic constants, the thermal expansion coefficients, and the strengths of two- and three-dimensionally reinforced composites.

The following documentation may be obtained from:

National Technical Information Service
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Reference:

NASA-CR-1324, (N69-24876), Zero Thermal Expansion Composites of High Strength and Stiffness

Source: N. F. Dow and B. W. Rosen of
General Electric Co.
under contract to
Langley Research Center
(LAR-10443)

Section 2. Structural Analysis

MASS LOADING EFFECTS ON VIBRATED RING AND SHELL STRUCTURES

Efficient methods for predicting the effects of attached masses on the vibration characteristics of ring and shell structures have been developed and substantiated with experimental data. Analytically, the series expansion technique is used in solving the mass-loaded shell problem, while both the finite-element and transfer-matrix methods are employed in the analysis of mass-loaded ring structures. Experimentally, aluminum ring and shell structures loaded with discrete masses are excited by an electrical induction force, and the vibratory motion is measured by an automatically revolving proximity gage. The influences of the masses of the exciter and of the instrumentation are thus eliminated. Response data are obtained with miniature accelerometers and with a proximity gage for comparison purposes. The studies show, in addition to the amplitude changes of the local vibration response caused by the addition of the discrete masses, the frequency shifts, the change of modal behavior, and the transmissibility character-

istics resulting from the increased discrete mass on the structure. The results show (1) that the response attenuation for the first mode is somewhat similar to the procedure currently recommended by NASA/MSFC for predicting the amplitude reduction of the local vibration response of unloaded structures, to account for the influence of the addition of the mass; (2) that for higher modes, much more amplitude reduction progresses very rapidly; and (3) that the transmissibility characteristics in a function of normal modes indicate some differences for beams, plates, honeycomb plates, rings, and shells.

Source: S.Y. Lee of
Rockwell International Corp.
under contract to
Marshall Space Flight Center
(MFS-14979)

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SHOCK AND VIBRATION RESPONSE OF A MULTISTAGE STRUCTURE

An analytical and experimental study has been made on the shock and vibration response of a multistage structure, in this case a space rocket vehicle. Analytically, lumped-mass, continuous-beam, multimode, and matrix-iteration methods were applied. Experimentally, a special technique was used in conjunction with a mechanical shaker. The study was made on the load paths, transmissibility, and attenuation properties along a longitudinal axis of a long, slender type of structure with increasing degree of complexity including ring frames, longerons, bulkheads, propellant fluid, payload mass (spacecraft), as well as multistage structures. Free vibration characteristics were analytically solved by lump masses and continuous beam approaches. A modal approach was applied to determine shock responses to various phases of different forms and durations for a multi-degree-of-freedom system. In the experimental phase

of the study, a special technique was employed to produce pulses of varying durations by a mechanical shaker. The test results verified the analytical predictions to a satisfactory degree.

Longitudinal forced response to various pulses of different forms and durations can be easily calculated for slender or multistage structures, as in bridge support towers, multistory building supports, and the like. Solutions obtained are peak responses and complete shock wave propagation along the axial stations within the structure.

Source: S.Y. Lee, S. Tang,
and J. G. Liyeos of
Rockwell International Corp.
under contract to
Marshall Space Flight Center
(MFS-14972)

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PEAK STRUCTURAL RESPONSE TO NONSTATIONARY RANDOM EXCITATIONS

A study was conducted to establish analytical expressions for the response of structures to severe nonstationary, random (transient) excitations. Impact loading of the landing gears and gust loading of an aircraft are typical examples of the excitations considered. Because of the relative severity of these excitations, prediction of fatigue and maximum response characteristics is an important part of the task of structural analysis and design.

The study established the distribution function of peak response values, based on a frequency interpretation. The distribution can be approximated by the Weibull distribution with the aid of the Monte Carlo technique, based on simulated peak values. By

this means, simplified expressions for the expected fatigue damage and the asymptotic distribution function of the maximum peak response of structures were derived. Applications of these simplified expressions are demonstrated by numerical examples in the report of the study.

Source: M. Shinozuka and J. N. Yang of
Caltech / JPL
under contract to
NASA Pasadena Office
(NPO-11617)

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ANALYSIS OF STABILITY-CRITICAL ORTHOTROPIC CYLINDERS SUBJECTED TO AXIAL COMPRESSION

An analytical procedure for determining critical buckling loads of orthotropic cylinders subjected to axial compression loading has been defined. Three modes of instability have been considered: general instability (a failure mode in which the total cylindrical structure collapses as a shell); local instability caused by panel and interframe buckling; and local instability caused by yielding and crippling in areas of stress concentration.

An analytical approach, employing the strain-energy solution, has been developed to analyze the general instability mode for determination of the load-carrying capability of a stability-critical, stiffened cylindrical shell structure under axial compression. The hoop extensional and flexural rigidities are expressed in terms of an equivalent isotropic cylinder thickness. This approach facilitates the derivation of the strain energy equations, and the development of a theoretical buckling stress equation for stiffened cylinders critical in general instability.

Local instability including interframe buckling and edge crippling failure modes which may be

evaluated by means of the established column or shell theory, as applicable to the specific structural configurations, has been appraised. Application of the theoretical buckling stress equation for general instability, and the resulting buckling coefficients for the ring-reinforced corrugated Saturn V/S-IC intertank models, have shown good correlation with test results. Correlation with test results from other sources (such as integrally-milled, waffle-stiffened cylinders; honeycomb-sandwich cylinders; mechanically-attached, Z-stiffened, ring-reinforced cylinders; and integrally-milled, externally-stiffened, ring-reinforced cylinders) has also been investigated.

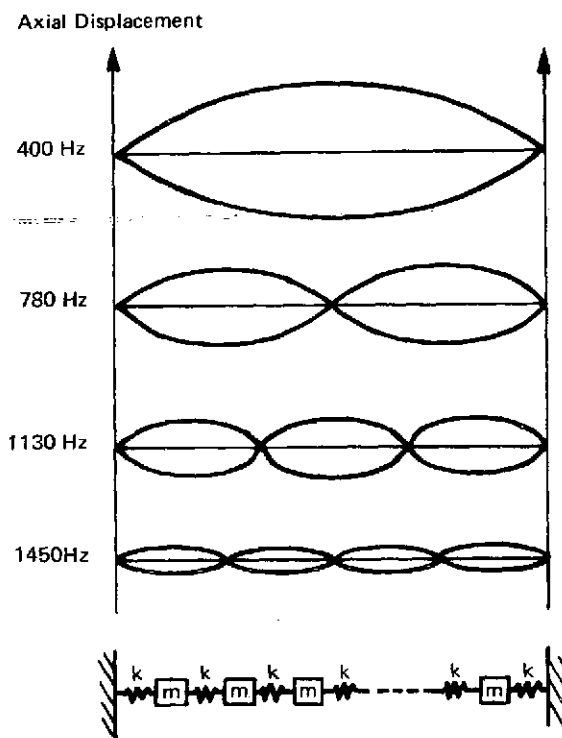
Source: R.L. Finley, L.S. Liu, and P.B. Yang of
The Boeing Company
under contract to
Marshall Space Flight Center
(MFS-12869)

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FLOW-INDUCED VIBRATIONS IN METAL BELLOWS

A phenomenon known as "vortex shedding" has been established as a prime cause in damaging, flow-induced vibrations occurring in metal bellows. When there is fluid flow over a cylinder with a sufficiently high Reynolds number a succession of alternately-shed vortices will occur in the near wake (upstream) region of the cylinder. Since the succession of internal tips of bellows convolutions essentially present a cylindrical configuration to fluid flowing through, "vortex shedding" takes place.

Laboratory experiments have confirmed that "vortex shedding," when at a frequency coinciding with one of the natural longitudinal resonant frequencies of the free bellows, can excite potentially damaging vibrations within the bellows.



In one test, a bellows was filled with water, capped off, and mounted on an electrodynamic shaker to identify its longitudinal natural frequencies. These are shown in the figure; 400Hz for the first mode, 780Hz for the second mode, 1130Hz for the third mode, and 1450Hz for the fourth mode. The significance is that the flow rate corresponding to each of the stress buildups results in a particular "vortex shedding" frequency that is close to or coincides with one of the longitudinal resonant frequencies of the bellows. These resonant modes are often referred to as the accordion modes. For the first four natural modes, axial displacement is plotted on the ordinate as a function of position along the bellows on the abscissa. The first natural mode is 400Hz. There are modes at the ends of the bellows and all of the convolutions are moving in phase with the maximum motion at the center of the bellows. The second mode is 780Hz with the nodes at the center and end points of the bellows, and the maximum motion is at the quarter points 180 degrees out of phase. The mechanical model shown at the bottom of the figure gives adequate predictions of the longitudinal bellows frequencies. The model consists of a series of equal springs (k) and masses (m) fixed at the ends. The individual springs can be determined from the axial spring rate of the bellows; the masses can be determined from the total mass of the bellows convolutions plus the mass of the fluid trapped in the roots of the convolutes. The mass and flexibility matrices can be determined from the model, and any standard eigenfunction routine will provide the resonant frequencies and mode shapes.

Source: H. J. Bandgren
Marshall Space Flight Center
(MFS-21331)

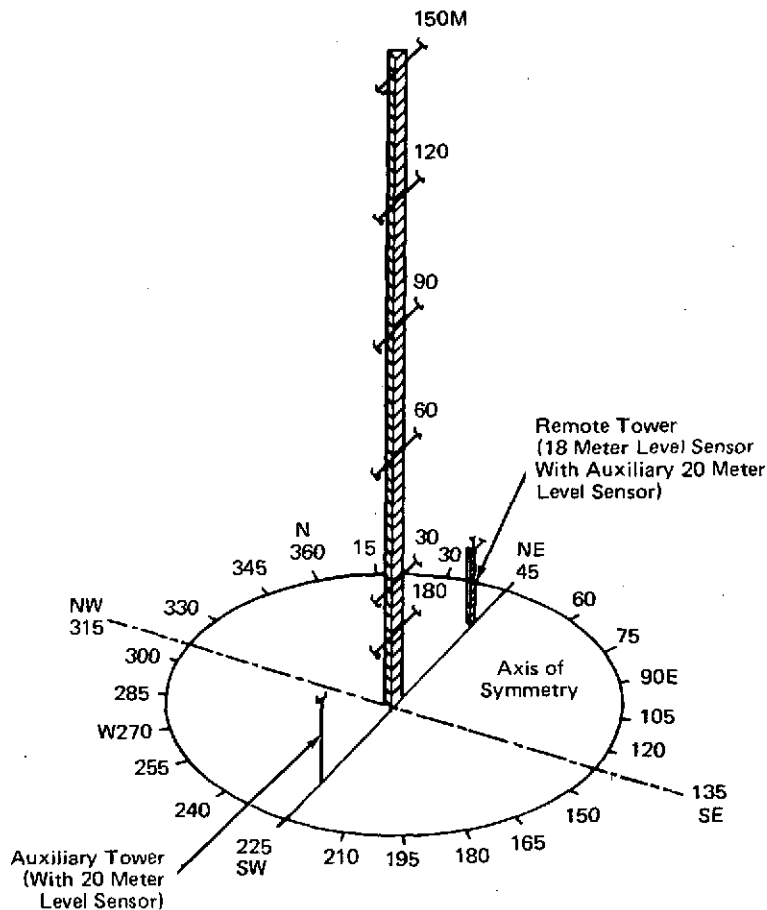
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WIND-TOWER INFLUENCE STUDY

A tall meteorological tower may significantly influence wind measurements as detected by sensors mounted on it at discrete elevations. It is necessary to correct these sensor measurements so their indicated

wind speeds and directions approximate the free-stream wind.

A set of correction factors can be applied to the measured mean wind speed and direction so that



close approximations of the mean speed and direction of the free-stream wind can be obtained. These correction factors can then be used to study quantitatively the amount of tower influence and to obtain any necessary speed and direction corrections. Experimentally, measured winds are compared to winds obtained from reference sensors in "undisturbed" locations. These locations are atop an auxiliary and a remote tower with both towers and their sensors (see fig.) aligned with the sensors on the meteorological tower.

In this study, a set of correction factors for wind speed was obtained by computing ratios of measured mean wind speed to reference mean wind speed. Also, a set of correction factors for wind direction was obtained by algebraically subtracting the measured mean wind direction from the reference wind direction. A supporting theoretical study was also performed to confirm the experimental work.

The experimental setup is shown in the figure. The meteorological tower is a 137-meter (457-ft.) steel lattice-type that supports wind sensors at several heights above the ground. Horizontal cross section of the tower is a 2.45-meter (8-ft.) equilateral triangle, and the wind sensors are attached at the tips of 3.66-meter (12-ft.) booms that extend northeast and southwest of the tower.

A wind director selector is employed to determine which sensor (northeast or southwest) is windward of the tower and to engage it for monitoring the wind.

Source: J. W. Hathorn of
The Boeing Company
under contract to
Marshall Space Flight Center
(MFS-20239)

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ANALYTICAL PREDICTION OF REVERSE BUCKLING PRESSURE FOR THIN SHELLS

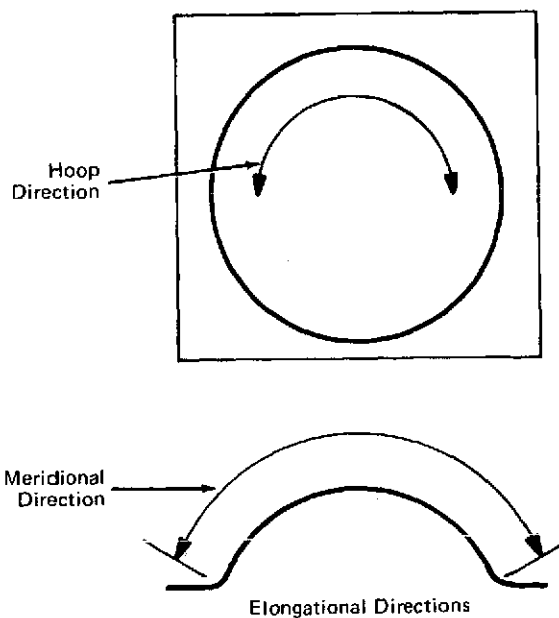
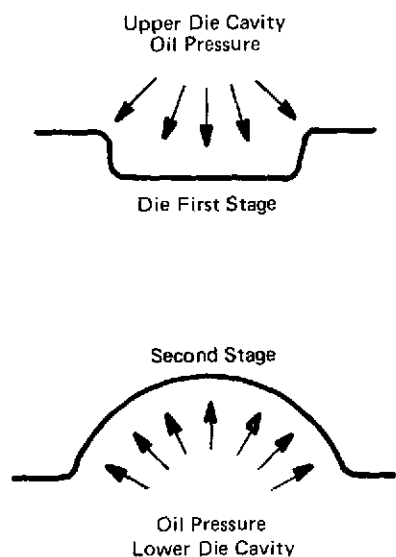
An analytical technique has been developed for the prediction of reverse buckling in thin curved shells. Empirical equations were obtained from burst-disk testing. Major considerations were material, material thickness, dome diameter, dome height, forming pressure, and reverse buckling pressure. Test data indicated that this technique predicts the actual reverse buckling pressure within 10% and should be of use for analytical prediction of reversed condition failure for problems such as explosive decomposition through vacuum failure.

This method is based on empirical information obtained from tests in forming hemispheres by extrapolation from test data on reverse snap buckling of the hemisphere. Initial data were obtained on elongation and yield strength of Inconel 600 foil along with the forming and reverse snap buckling pressures and the dome heights. The elongation in the shell takes place in the meridional and hoop directions (see fig.); meridional and hoop elongations were assumed to be equal, then combined and subtracted from the initial material elongation to provide a residual elongation. The residual elongation

was used to determine the equivalent yield stress from data (a curve) established from other research. The forming pressure required could then be calculated from the equation for a hemispherical pressure vessel.

The reverse snap buckling pressure is a nonlinear function; an empirical curve was established, but was limited to a geometrical parameter (λ) equal to ten, where λ is a nondimensional ratio of the chord, thickness, radius, and Poissons ratio. For the technique being described, λ varied from 30 to 44, but combined data indicated a good correlation.

Chord lengths were obtained by measuring the reflected image of the hemisphere on a comparator, and the material thickness was obtained by measuring with pin micrometers. The radius, half angle, and arc length were calculated from equations. The dome-wall (diaphragm) thickness from the chord to the crown varied from approximately 17% to 33% respectively. The mean thickness value was empirically determined to be at the centroid of the dome where one-half the included angle is equal to 38° . This averages out to 23.5% thinning of the initial



material thickness. The variations in thinning from chord to crown indicate that the cold work varies directly as the thinning rate. For these reverse buckling calculations, the empirical thinning value of 23.5% indicated reverse buckling pressures within 10% of tested values.

The following documentation is available from:
National Technical Information Service
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Reference:

NASA-TN-D-3212, (N66-17733) A Nonlinear Theory of Bending and Buckling of Thin Elastic Shallow Spherical Shells.

Source: C. Urbanac and D. L. Martindale of
AMETEK/Straza
under contract to
Kennedy Space Center
(KSC-10515)

STABILITY OF STRUCTURAL RINGS UNDER UNIFORMLY-DISTRIBUTED RADIAL LOADS

An energy-method analysis establishes the parameters governing the stability of circular rings acted upon by constant, uniformly-distributed radial loads. The energy method was used so that the nonlinear behavior of the structure prior to buckling could be accounted for. In addition, this method affords a conceptually superior basis for analyzing the axisymmetric deviation mode. The analysis requires that the number of displacement variables used in the equation for the total strain energy in the ring be the smallest possible that will still lead to a realistic description of the expected behavior.

One example is a ring stiffener in a thin-walled shell of revolution subjected to external pressure. The displacements of the ring depend upon the relative stiffness of the shell in and out of the plane of the ring. The problem, then, is that of determining the stability of a ring acted upon by a uniform radial load and subjected to both in-plane and out-of-plane displacements that may be constrained.

It is important that in-plane and out-of-plane displacements be given the same emphasis in a study of their interaction during buckling. For this reason, the displacements of the ring are described in terms of the displacements of its centroidal axis and the rotation (twist) of the cross section about that axis.

In general, the analysis shows that critical mode shapes are a combination of in-plane and out-of-plane displacements and that they occur at loads considerably below the classical (in-plane) critical load. For symmetrical cross sections, the critical load for the constrained ring is greater than that for the corresponding unconstrained ring.

The following documentation may be obtained from:

National Technical Information Service
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Reference:

NASA-CR-107848 (N70-17318), The Stability of Circular Rings Under a Uniformly Distributed Radial Load

Source: H. E. Williams of
Caltech / JPL
under contract to
NASA Pasadena Office
(NPO-11396)

BUCKLING STRENGTH OF FILAMENT-WOUND CYLINDERS UNDER AXIAL COMPRESSION

Experimental data have been previously obtained on buckling of filament-wound cylinders having diameter-to-wall thickness ratios ranging from 25 to 304. A reasonable comparison was, in general, achieved between predictions by small deflection orthotropic shell theory and test data. Additionally, it has been noted that a coupling occurs between shear failure and buckling when resin stresses are high enough at the buckling load to cause plastic flow in the resin.

A more recent experimental and analytical study has involved the effects of axial compression on eleven filament-wound cylinders having diameter-to-wall thickness ratios of 167 to 643, the wall structures consisting of three composite layers. One layer is a polar wrap consisting of two half layers at angles (offset with respect to the longitudinal axis of the cylinder) and is enclosed by an inner and an outer circumferential wrap. Each of the three layers is of the same nominal thickness. This combination is efficient in the presence of internal pressure and minimizes the effects of initial imperfections on buckling strength by providing circumferential in-plane and bending stiffening. Also, cylinders whose middle layers are not oriented axially produce an anisotropic coupling between stretching and shear.

Analytical predictions for buckling loads were obtained by using linear anisotropic shell theory. The results of the compression tests indicated that the cylinders buckled at 65% to 85% of the loads predicted by classical linear analysis. The buckling

mode was coupled with catastrophic shear failure in the smaller cylinders, while the larger cylinders buckled into the classical diamond-shaped pattern with the basic integrity of the cylinder maintained.

The composite moduli required for the buckling analysis were determined for each cylinder from experimental test data obtained by the classical method of using three tests: torsion, internal pressure, and axial tension or compression. It was demonstrated analytically that the anisotropic coupling between stretching and shear only influences the determination of the moduli by terms of the order of the square of the ratio of the thickness of the cylinder to the radius of the cylinder. Thus, because of the thinness of the cylinder walls, the anisotropic coupling was found to have a negligible effect on the experimental determination of the moduli.

The following documentation may be obtained from:
National Technical Information Service
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Single document price \$6.00
(or microfiche \$0.95)

Reference:

NASA-CR-266, (N65-28956), "The Buckling Strength of Filament-Wound Cylinders Under Axial Compression" by J. Tasi, A. Feldman, and D. A. Stang.

Source: HQN-10032

NONLINEAR DAMPING IN STRUCTURES

An analytical and experimental study of the dynamic responses of a structure with nonlinear and nonproportional damping has been completed. The analysis showed that the steady-state solution of structure, with damping at its boundary, can be obtained from the undamped vibration solutions, and that if nonproportional damping is low, classical normal mode responses can be indicated by the derived general solution. Analytical results were used to develop experimental approaches to determine

damping properties of substructures or structural elements. Experimental studies were used to demonstrate the developed techniques, and results proved the feasibility of measuring damping for its components and for obtaining an accurate overall structural damping prediction. While the analyses and experiments were confined to a beam-like structure, they could be adapted easily to other configurations commonly encountered in industrial structures.

For complicated structures, it is impractical to

determine local damping properties from dynamic tests of the assembled structure, primarily because many actual dissipative processes in structures are nonlinear in nature, and because the distribution of damping mechanisms is usually not proportional to any linear combination of inertia and stiffness matrices. Consequently, the responses of such structures are not solutions of uncoupled modal equations of motion, and local damping properties must be determined by physical substructuring and testing. In general, a substructure or structural element can be so chosen for damping and stiffness measurements that it contains only one relatively simple, continuous member, with one or more boundary conditions, representing mechanical joints used to connect the substructure with others in the parent structure. For the substructure, damping is due to dissipations which occur within material elements, across joint interfaces (including boundary joints), and over solid-fluid interfaces. In most cases, damping for the substructure is still nonviscous, amplitude-dependent, and nonproportional. Because of the simplicity of the substructure, however, the analyses required for damping property measuring experiments can be developed, even with such complications. This is the principal advantage of testing substructures rather than complete structures.

To predict dynamic responses of the parent structure modeling (analytical representation) of structural elements presents relatively minor difficulties, especially in light of recent developments in applications of finite element methods. The success or failure of an analysis is critically dependent upon success or failure in modeling structural joints, particularly in assigning correct stiffness and damping values for joints. Substructure and joint testing will provide the desired information which cannot be easily obtained by any other means. A strong case can be presented for preferring analyses (or model testing) in combination with substructure tests, over performing full-scale tests, on the basis of better

accuracy and more meaningful results attainable, usually at lower costs. The analysis of a simple beam with a dissipative end condition leads to simple solutions that are easily related to physical properties of the structure. The method of analysis appears to be equally applicable for other structural components, as well as for substructures of greater complexity than rods, beams, and plates. Based on such considerations, definitions of modal responses and modal coefficients, etc. (which can be related to physical properties of structures) were proposed for the case of nonproportional damping. If nonproportionality is small, modal coefficients can be assumed to be constant, even if total damping is not low.

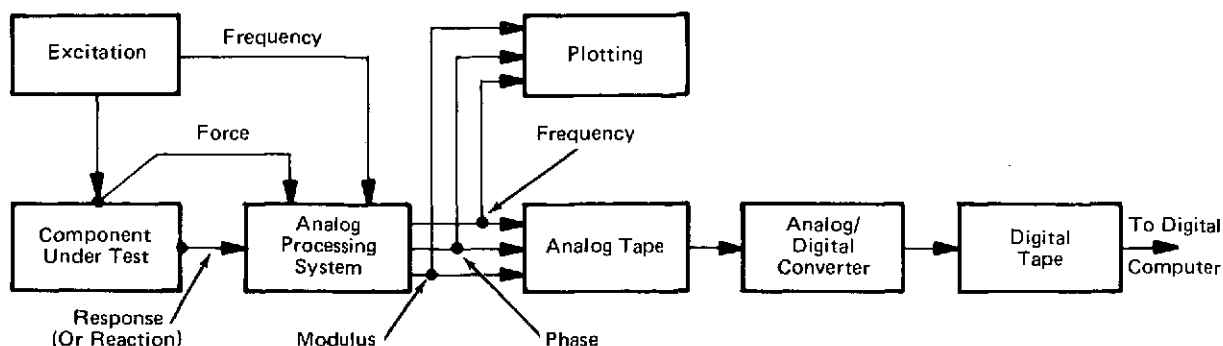
The experimental demonstration of the test approach of physically substructuring complicated structures and testing them and their joints individually was successful for the specimens employed. This success leads to the postulation that substructure testing and analyses may eventually replace expensive tests of totally assembled complex structures. Advantages of substructure testing are clear: local properties are directly measured and specimens are less costly and more easily tested with better controlled tests and environments.

This modeling technique presents a relatively uncomplicated method for analysis of real-case models, and may be of use wherever complex vibratory problems are encountered. The information should interest personnel in the aircraft, marine, and high speed ground transportation industries, and manufacturers of high speed machinery.

Source: C. S. Chang of
Lockheed Missiles and Space Co.
under contract to
Marshall Space Flight Center
(MFS-20701)

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ANALYSIS OF STRUCTURES USING THE TRANSFER-FUNCTION CONCEPT



In large, complex structural systems, it is not feasible to make meaningful analysis of dynamic and vibrational response, although the most modern, sophisticated computers are used. A new approach divides the system into suitable subsystems, determines the dynamic and vibrational response of the individual subsystems, and then, by use of frequency transfer functions (the steady-state response at one point due to a unit amplitude sinusoidal input at another point), determines the vibrational response of the whole system by transfer-function coupling.

The subsystem transfer functions can be determined either by analytical or experimental techniques. In the analytical determination, a modal analysis gives the normal modes representing the response, the modal frequencies, and the generalized masses; the appropriate boundary conditions are imposed during the modal analysis as required by the assumed model.

Experimentally, as shown in the diagram, the transfer functions are determined by exciting the subsystem at a point with a shaker, producing an input force that closely approximates a sine wave; the frequency is slowly varied while monitoring the output response. The modulus of the output/input ratio and the phase angle between the input and output are recorded.

The matrices of the subsystem transfer functions involving respectively, response and excitation points, response and coupling points, only coupling points, and coupling and excitation points are then formed to obtain the complete system matrix. This matrix is then prepared for computer processing which performs computations of the component and system matrices, the deterministic time response, or the spectral densities due to random excitations for the coupled system.

The technique of transfer-function coupling of subsystems is particularly useful in connection with experimental work in which only the subsystems are amenable to measurements and the experimental equipment substantially influences the measured results.

Documentation is available from:

National Technical Information Service
Springfield, Virginia 22151
Price \$3.00
Reference: TSP69-10337

Source: E. Heer and M. R. Trubert of
Caltech / JPL
under contract to
NASA Pasadena Office
(NPO-11162)

OPTIMUM STRUCTURAL DESIGN BASED ON RELIABILITY AND PROOF-LOAD TESTING

Thermomechanical properties (such as fracture strength, elasticity modulus, and deformation capacity) of materials used in the structure of vehicles exhibit considerable statistical variations. Furthermore, severe environments and loading conditions involve a number of uncertainties as to temperatures generated by aerodynamic friction, dynamic pressures, axial accelerations, and vibration loads. This indicates that both the strength of a structure and loads acting on the structure should be treated as random variables and that the concept of structural reliability should be incorporated into the analysis of the structure and its optimum design. The major structural components of a vehicle are usually tested individually, or otherwise under simulated environmental and loading conditions before the vehicle is deployed. Since such simulated tests or proof-load tests are indispensable parts of the engineering task within a test program, it is extremely important that the effect of such tests be taken into account in the estimation of structural reliability and in the structural design. This study presents quantitative results of weight saving and increased reliability by taking into consideration the proof-load test.

From the viewpoint of reliability analysis, the performance of the proof-load test can improve not only the reliability value itself but also the statistical confidence in such a reliability estimate. This is because the proof-load test eliminates structures with strength less than the proof load. Therefore, it is obvious that the reliability of a structure chosen from this subset is higher than that of a structure chosen from the original population. Further, the proof-load test truncates the distribution function of strength at the proof load, thereby alleviating the analytical difficulty of verifying the validity of a fitted distribution function at the lower tail portion where data are usually nonexistent. Obviously, the difficulty still remains in the selection of a distribution function for the load. However, the statistical confidence in the reliability estimation now depends mainly on the accuracy of the load prediction. Rational methods to

deal with the statistical confidence of the load distribution are discussed in detail and the Bayesian approach is suggested.

An approach is developed for optimizing a structural design (for either minimum weight or minimum expected cost) by introducing the proof load as an additional design parameter, and the practical advantages of the use of proof loads in terms of weight saving are demonstrated by numerical examples. The importance of the proposed method in structural design is emphasized because it represents a truly rational approach in an area clouded by uncertainties. Moreover, it establishes a definite design procedure applicable to most aerospace structures.

Although the present study places its emphasis on the problem of optimization of aerospace structures, the principle involved can be applied to optimization problems in other engineering disciplines (such as design of civil engineering structures, naval structures, ground vehicles, material-handling equipment, and electronic systems). In particular, the optimization can be highly significant for electronic systems consisting of thousands of components when the cost of each component is so small in comparison with the total cost of the system that a relatively high level of proof load can be applied.

The following documentation may be obtained from:

National Technical Information Service
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Reference:

NASA CR-103423 (N69-32368), Optimum Structural Design Based on Reliability and Proof-Load Testing

Source: J.N. Yang and M. Shinezuke of
Caltech/JPL
under contract to
NASA Pasadena Office
(NPO-11228)

ANALYTICAL PROCEDURE FOR ESTIMATING RELIABILITY OF RANDOMLY EXCITED STRUCTURES

An analytical procedure for predicting the reliability of structures under stationary random excitations has been developed. The analysis takes into account the statistical variation of the material strength and the interactions between the catastrophic and fatigue failure modes, which have not previously been considered in random vibration analyses.

The analysis employs the concepts of fracture mechanics and extreme point processes associated with stationary narrow-band random vibrations. Since the statistical variation of material strength is an important factor in determining the structural safety,

disregarding this factor and the failure modes interactions yields a nonconservative estimate of reliability. This estimate tends to become more critical with increasing flaw propagation factors or statistical dispersion of the material strength.

Source: J. N. Yang and E. Heer of
Caltech/JPL
under contract to
NASA Pasadena Office
(NPO-11618)

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STRUCTURAL BEHAVIOR OF TAPERED, INFLATED FABRIC CYLINDERS UNDER VARIOUS LOADING CONDITIONS

In developing structural analysis methods of inflatable structures, it was found that classical methods long used for rigid structures did not apply. The material from which an inflatable structure is ordinarily fabricated is neither isotropic nor orthotropic but is anisotropic in behavior. Furthermore, when nonmetallic materials are used, the large deflection behavior of the structure must be accounted for as a result of large strains at the design stress level. Thus, an analytical method for predicting structural behavior of linearly variable (tapered) cross sections under various loadings was required.

This innovation is the first method of analysis for such members and considers axial loads (tension, compression, Euler effect), torsional moment, and internal pressure. The behavior is dependent on the anisotropic nature and the large deflection stress-strain

characteristics of the fabric material. The equations of behavior for a pressurized cylinder loaded in torsion are developed. The limiting torsional moment (including the influence of nonlinearity, permanent set, and history of loading) and other loading conditions such as bending and axial load are considered.

This material may be of interest to architects, civil engineers, and the fabric industry.

Source: F. L. Risk and L. Kovalevsky of
Rockwell International Corp.
under contract to
Johnson Space Center
(MSC-15317)

Circle 18 on Reader Service Card.

STATIC STRUCTURAL ANALYSIS OF SHELL-TYPE STRUCTURES

A manual has been prepared that is, essentially, a condensation of material published by U.S. Government agencies, universities, and aerospace industries, and in scientific and technical journals both domestic and foreign. The manual is arranged in 5 chapters.

Chapter 1.00 presents a derivation of general shell theory from concepts of the linear theory of elasticity and includes the basic relationships of shell geometry, geometry of strain, stress-strain, and equilibrium. The various shell theories are classified according to the simplifications made to a higher-order theory. Approximate theories and simplifications that have made the solution of these theories possible are delineated. A presentation of nonlinear shell theory to be used for large deflection analysis of shells is included. This development is based on variational principles and the concept of stationary potential energy. Structural stability shell theory is discussed. The shell stability equations are presented and techniques for determining buckling loads using variational procedures are outlined. A discussion of the discrepancies between the theoretical and experimental results is included.

In Chapter 2.00, instructions, procedures, basic solutions, and recommendations are presented to determine static deflections and internal load and stress distributions in shells under various loading conditions. This chapter also includes membrane solutions for various loading conditions, unit edge loading solutions, and combined solutions for various shell geometries and constructions, loadings, and boundary conditions. Factor-of-safety concepts, failure criteria, and margin-of-safety calculation under uniaxial and biaxial loading conditions are also presented.

Methods of analysis for the static instability (buckling) of shell structures are presented in Chapter

3.00. This chapter presents methods for obtaining the design allowable buckling loads for unstiffened cylinders, cones, spherical caps, and curved panels under various loading conditions. Also included are procedures for the stability analysis of orthotropic shells, stiffened cylinders, and sandwich shells. Analyses for inelastic buckling and combined loading conditions are also presented.

Chapter 4.00 presents methods of analysis to be used in preliminary design to determine the lightest shell wall for various constructions subjected to specific loading conditions. A survey of pertinent literature is also included in this chapter.

An introduction to the fundamentals of computer utilization is presented in Chapter 5.00. The basic computer characteristics are described. An introduction to matrix algebra is included in this chapter, in addition to a description of the techniques used in solving shell problems and discussions of the use of computers in conjunction with these techniques.

The following documentation may be obtained from:

National Technical Information Service
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Reference:

NASA-CR-912 (N68-24802) Shell Analysis
Manual

Source: F. L. Rish, E. H. Baker
A. P. Cappelli, L. Kovalevsky,
and R. M. Verrette of
Rockwell International Corp.
under contract to
Johnson Space Center
(MSC-11555)

IDENTIFICATION AND EVALUATION OF LINEAR DAMPING MODELS IN BEAM VIBRATIONS

Effective linear damping models in beam vibrations have been investigated in the areas of viscous, stress, and load damping. The purpose was to model mathematically the dynamic response of a beam-type element in which significant dissipation of energy could be attributed to contact of the component with adjacent similar components.

An example of such a case is a nuclear-reactor core consisting of many structural elements, usually in the form of slender plates or rods containing the fuel. These fuel elements are often arranged in small subassemblies, which in turn are mounted on a support grid to form a relatively tightly-spaced bundle. High-velocity coolant flows axially through this arrangement and can induce vibratory motion of the subassemblies. Study of the vibration response requires among other things a mathematical representation of the damping, or dissipation of energy.

The usual method of modeling damping was employed, that is, assumption of damping mechanisms and empirical evaluation of the coefficients. The problem was in identification of the dominant damping mechanism or mechanisms — viscous, stress, and load — for inclusion in the mathematical model, and in evaluation of the associated damping coefficients.

A theoretical analysis was based on the usual assumptions in beam theory (Euler), and on the further assumption that the damping is so little that the natural frequencies and mode shapes are unaffected. The analysis led to a sensitive method, compatible as to results with tests with a vibration exciter, for identifying the effective damping mechanisms. The technique involves comparison of the experimentally determined ratio of first- to second-mode magnification factors, related to a common point on the beam, with the constant values of this ratio corresponding to "pure forms" of the proposed damping.

Study of the interaction and damping, with a full-size mockup of a core, was prohibited by the high cost of fabrication of prototype fuel elements. Therefore the method was illustrated by application, to the modeling, of the response of a cluster of cantilevered beams clamped together at the base. This model was employed in the preliminary analysis of the interaction effects of vibrating rods in the nuclear-reactor core. Damping models were identified, and curves of damping coefficients as a function of cluster size are presented. The results show that:

(1) The cluster size (and hence the interaction phenomena) has little if any effect on the natural frequencies of an individual element within the cluster;

(2) The magnification factor, related to the free end of the rod, decreases continuously with cluster size, but appears to approach a limiting value;

(3) In the attempt to determine the scale of experiment required to give results typical of a full-size core, the only invariant observed was the ratio of first- to second-mode magnification factors. The magnitude of this ratio indicates that viscous and stress damping may be the dominant damping mechanisms for the particular case studied.

The following documentation may be obtained from:

National Technical Information Service
Springfield, Virginia 22151
Single document price \$6.00
(or microfiche \$0.95)

Reference:

ANL-7292 (N68-20144) Methods for Identifying and Evaluating Linear Damping Models in Beam Vibrations

Source: M. W. Wambsganss, Jr., B. L. Boers,
and G. S. Rosenberg
Reactor Engineering Division
Argonne National Laboratory
(ARG-10275)